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The role of ground beetles (Coleoptera: Carabidae) in monitoring programmes in Australia

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Use of the diverse Australian carabid fauna in environmental assessment is at present restricted, because of lack of ecological and faunistic information and the difficulties of identifying most taxa. They are not yet a core focal group in monitoring studies. In contrast to groups such as ants, in particular, many carabids are usually captured in only small numbers, and functional groups of Australian Carabidae are poorly defined. Although a few studies have demonstrated the predominance of particular taxa in local assemblages and their responses to changes in land management, the presence of particular taxa and the richness of assemblages is unpredictable because of lack of knowledge of habitat requirements. The general usefulness of carabids as indicators in Australia is not yet proven. Carabidae are one of several groups of epigaeic invertebrates with potential for incorporation into a portfolio of focal groups for environmental assessment, but are still far from being a 'stand alone' group in Australia.

1. Introduction

The use of Carabidae (ground beetles) for environmental assessment in Australia has received little attention, and is by no means as common as in much of the northern hemisphere, where considerable ecological interpretation at species and assemblage levels has been undertaken. There, carabids are one of the most important insect groups used as indicators in many terrestrial ecosystems (Stork 1990, Desender *et al.* 1994). Despite their undoubted values and potential as monitors in some environments, their use in Australia is not likely to increase substantially during the next few years, at the least. In this paper I explore why this is so, in the context of a broader summary of the use of terrestrial epigaeic invertebrates in conservation assessment in Australia, especially of their values in helping to evaluate habitat quality. Most of the problems of employing carabids result simply from our ignorance of the group, and of the responses of individual species to habitat change at even very broad levels. As elsewhere, they are among the widespread groups of epigaeic insects amenable to trapping by relatively simple techniques, appear to show strong relationships with particular habitats, and which also occur reasonably strongly in heavily altered landscapes. Carabidae, simply, merit increased study to determine their worth as ecological tools in Australia. Such studies must encompass the biology of the more abundant taxa and seek to define the characteristic carabid assemblages of a variety of vegetation types and microhabitats.

2. The Australian Carabidae

The Australian Carabidae are a remarkable element of the diverse beetle fauna of the isolated island continent, with many phylogenetically important taxa. Carabidae are by no means the largest family of beetles in Australia, but still comprise an impressive, and very approximate, 2500 species. Many of these are undescribed, although the listing in the Zoological Catalogue of Australia (Moore *et al.* 1987) enumerates 266 genera and about 1800 described species, many with additional synonyms. More recent revisionary studies have extended the described fauna to slightly over 2000 species. Much of the basic descriptive taxonomy does not incorporate biological information, and there have been few complementary ecological studies and surveys of ground beetles. Basic inferences on regional diversity, local species richness, and distribution patterns of most groups are fragmentary or non-existent. The detailed templates of species incidence and seasonal patterns taken for granted by entomologists working on carabids in parts of Europe simply are unavailable.

Likewise, there is relatively little non-specialist literature on the family. Matthews (1980) provided keys to the genera that occur in South Australia, and Moore (1980) included a general appraisal of the family in his book. A rather more technical account, with keys to tribes, is provided by Lawrence and Britton (1994). However, almost universally for species level studies, the information needed to identify species is in the primary literature, or does not exist in any synthesised form. Some groups, such as Harpalinae, are particularly difficult to identify. Even separation to generic level is difficult without access to a large institutional collection and, as for many other groups of insects in Australia, the overall taxonomic impediment and dearth of secondary guides largely precludes reliable non-specialist identifications of Carabidae. Few larvae are recognisable to species level, and life history data are fragmentary even for many of the most common species.

As Moore *et al.* (1987) noted, many of the larger genera have not been subjects of any recent revision, and contain varying amounts of undetected or undocumented synonymy, in addition to undescribed taxa. The solid descriptive foundation on Australian Carabidae laid earlier this century in a series of some 50 papers by T. G. Sloane is difficult for a non-specialist to digest. Sequences of papers more recently by B. P. Moore and M. Baehr, in particular, have made notable advances to our knowledge of some groups, and their distributional relationships. Cicindelinae were appraised by Freitag (1979), so that the 29 species of *Cicindela* L. can be recognised clearly, and the other genera of this small subfamily diagnosed. However, by far the majority of Australian Carabidae belong to the Carabinae (with 32 tribes recognised: Lawrence & Britton 1994).

As with many insect groups, endemism in Australian Carabidae is very high. A high proportion of species is geophilous, although recent studies in northern Queensland have greatly increased the known diversity of arboreal species (such as the species of *Philipis* Erwin: Baehr 1995). Many taxa appear to have very restricted distributions. *Notonomus* Chaudoir, for example, contains around 100 described species, all flightless and many limited to forest environments in eastern Australia. In these habitats, there is considerable species turnover along latitudinal and other gradients, as demonstrated by Darlington (1961).

The broad geographical pattern of Australian carabids is one of older elements in the south of the country, reflecting persistence of Gondwanan elements in the Bassian region and various degrees of northern incursives (taxa with strong relationships to the faunas of Indonesia, Papua New Guinea and, more broadly, the Oriental region) extending from north to south. However, many species appear to be uncommon, and are known from few specimens and, in some cases, from only their type locality. Their distributions are essentially unknown except in the most general terms, and usually lack strong ecological correlates at smaller scales.

Ecological specialisations include a substantial troglobiont fauna, with local taxa in caves in many different parts of the country — including local endemics in Tasmania, New South Wales and the Nullarbor Plain. *Speotarus princeps*, for example, has been recorded from a single cave in New South Wales, in which recent searches by Eberhard and Spate (1995) failed to locate it. Several obligate cave dwellers are listed as 'Vulnerable' on Tasmania's interim list of threatened invertebrates (IAC 1994). Many of the intriguing cave-dwelling carabids have been described by Moore over the last 35 years.

Likewise, the flightless forest taxa, both geophilous and arboreal, tend to be highly localised. They were incorporated by Monteith (1995) in developing a conservation index for evaluating and ranking the highly sensitive tropical wet forest areas of Queensland. However, in those areas, arboreal taxa (collected by insecticide fogging of tree trunks: method summarised by Baehr 1995) were the predominant fauna collected.

There is little definitive information on carabid phenology, simply because surveys and detailed life history studies have only rarely been done, even for many of the most abundant species. Near Melbourne, *Notonomus gravis* (Chaudoir) has been captured in every month of the year (P. A. Horne, 1992), but in very small numbers during winter compared with mid-summer. As P. A. Horne (1990, 1992) noted, the population has overlapping cohorts of current year and previous year adults and this feature, together with many females being inactive for parts of their life by caring for their brood (so that they are then not accessible to pitfall trapping) renders interpretation of population size and sex ratios difficult. For such brood-tending taxa, which are probably numerous among Australian pterostichines (Horne 1990), differential activity of the sexes may be the main cause of variations in pitfall catches.

3. Conservation evaluation

Considerable attention has been paid in Australia to facilitating the use of terrestrial invertebrates in evaluating and characterising habitats and landscape change (Yen & Butcher 1997, for overview). In evaluating the importance of both cave faunas and forest assemblages, as above, carabids are simply one group of many invertebrate taxa employed, and their use as sole tools in these contexts seems comparatively limited, notwithstanding the values of particular notable taxa which could themselves be targeted (for example by some form of listing on protection schedules) for individual conservation. The lack of detailed biological knowledge of any given taxonomic group can in part be offset by using a combination or suite of different, complementary groups for evaluation of any major habitat. The particular groups involved will clearly differ in different contexts, but should preferably incorporate taxa which show some ecological complementarity and can be sampled straightforwardly by simple, standardised techniques (New 1993, 1995, 1998). This context is currently receiving considerable attention in evaluations involving invertebrates in Australia. In altered landscapes, such as those heavily modified for intensive agriculture or softwood plantation forestry (mainly of the exotic Monterey pine, *Pinus radiata*) in the southeast, dramatic changes in the epigaeic invertebrate fauna can result. Considerable effort has been made to evaluate and document such changes, and to implement monitoring systems involving the responses of different invertebrates and invertebrate groups.

However, there is one important restriction on the interpretation of these. Virtually all studies have been undertaken in those parts of the continent already subject to massive alteration by changes in land use patterns since European settlement over the last 200 years (Greenslade & New 1991, Graetz *et al.* 1995). These areas have been subjected to massive despoliation and invasion by exotic biota (not including carabids), and much of it bears little resemblance to its condition of only a century ago. For some critical ecosystems now represented by only small disjunct remnants, it is difficult to obtain reliable baseline data against which to evaluate the extent of faunal change. Methods for interpretation involving invertebrates are still being developed, drawing in part from lessons learned from other parts of the world.

As one example of habitat change, native grasslands in Australia's southeast are regarded widely as one of the country's most endangered terrestrial ecosystems (Kirkpatrick *et al.* 1995), and estimates of 93%–97% of the grasslands being lost, predominantly to pastoralisation and exotic grass species, indicate the likely extent of parallel disruption to native invertebrate communities. Data for changes in Carabidae are rather sparse but, for example, using the Golden Sun Moth (*Synemon plana* Walker, Castniidae) as a flagship species for high quality native grassland, it is clear that this species has disappeared from many of the sites it formerly inhabited, and is now present almost entirely on a small number of remnant patches. Another flagship species in the same habitat is the flightless morabine grasshopper, *Keyacris scurra* (Rehn).

Extensive pitfall trapping in such areas generally reveals rather few species of Carabidae, many of them very sporadic in incidence. The same situation prevails in open woodlands and agricultural lands. Horne and Edward (1997) found 28 species of Carabidae, some of them commonly, in a year of pitfall trapping in agricultural land in western Victoria and believed some of these to be important predators of pest arthropods. Indeed, conservation tillage practices may even enhance the abundance of some species such as *Rhytisternus liopleurus* (Chaudoir) over conventional tillage treatments (Horne & Edward 1998). Near Melbourne, in an even longer period of pitfall trapping, Horne (1992) recovered only 15 carabid species, and over one season more than 80% of the 1939 individuals were *Notonomus gravis* (Chaudoir). Likewise, in the Australian Capital Territory, B. A. Melbourne (unpubl., cited by Melbourne *et al.* 1997) found 24 species, representing 22 genera. Ordination analyses indicated that two types of introduced grassland were characterised by essentially the same carabid assemblage, although assemblages were somewhat more distinctive on some different native grasslands. However, each of Melbourne's grassland sites supported rather few species (range 2–9) and (as in Horne's studies noted above) a very high proportion of total carabids (735/972) was a single species, *Notiobia edwardsii* (Castelnau).

Similar inferences may be drawn from studies in forests. Thus, only 18 of Tasmania's approximately 220 species of Carabidae were trapped in a survey of eucalypt forests in the Picton Valley in a survey involving 14 sites over 10 months (Michaels & McQuillan 1985), and only two of these were widespread and abundant. The assemblage in forest patches in New South Wales comprised 45 species (Davies & Margules 1998).

Such results emphasise that many species present may be scarce, so that — if we neglect such rare taxa of uncertain incidence and consequent low monitoring value — few species of Carabidae may be useful as reliable monitors of habitat change. Partly because of this, Carabidae have attracted rather little attention compared to several more diverse and abundant groups, such as Collembola (Greenslade 1997) and ants (Andersen 1997b), or to a variety of other groups reported in some surveys.

4. Monitoring

The twin needs for monitoring in terrestrial habitats using invertebrates in Australia both draw on the common presumption that invertebrate responses may be among the most sensitive indicators of environmental change and, hence, of 'ecosystem health'. These needs are:

1. Determining the influences of changes in land use, including determining the levels of degradation in relation to pristine areas, monitoring attempts at restoration, estimating the conservation value of private land, providing inventory information and basic documentation to assess the value of protected areas and remnant habitat patches, detecting spread of exotic taxa and their impacts, and broad evaluation of conservation management.
2. Determining change along environmental gradients, including altitudinal gradients as possible harbingers of climatic change, and latitudinal gradients, as well as more local scenarios such as studying the effects of habitat edges and barriers resulting from development.

In attempting to determine whether a particular taxonomic group merits attention as an 'indicator', the suggestion by Kremen *et al.* (1993) of examining responses across a steep environmental gradient is an expedient way to proceed. 'Gradsect analysis' (Gillison & Brewer 1985) is the deliberate selection of transects which contain the steepest environmental gradients present in an area, to ensure sampling of the greatest range of variables; in their initial example, of vegetation, Gillison and Brewer showed that gradsects captured more information than randomly placed transects of similar lengths. C. Helman (unpubl., as cited in Austin & Heyligers 1989, 1991) concluded that this approach is sound for surveying rainforest patches, based on altitudinal gradients from the coast to the tablelands of New South Wales, and using the initial assumption that altitude was the major gradient. Within a gradsect other factors (such as substrate, size of habitat patch and degree of isolation) may determine the precise sites for replicated sampling, because many such factors may not be included in the initial selection criteria for the gradient. A selection procedure is discussed in detail by Austin and Heyligers

(1991) and could form the basis for appropriate designs for arthropods. For Carabidae, vegetation type and gross level of disturbance might be valid for gradsect selection, but the multitude of local factors which influence the incidence and abundance of particular species must eventually be superimposed on this.

There is urgent need to determine a series of 'focal groups' which can be used validly in such studies, and to establish adequate sampling protocols for their effective use. As noted earlier, good baseline data involving carabids are sparse. Even for highly sensitive and vulnerable areas, such as Australia's restricted alpine zone (about which there is considerable concern over intensifying development for winter sports and its likely decline with global warming), most groups of invertebrates have not been enumerated comprehensively despite many species being limited to those environments. Some unusual flightless Carabidae are narrowly endemic to alpine habitats.

Ants are by far the most widely documented group of insects involved in broader appraisal of epigaeic faunas in Australia, and influences of habitat change, predominantly through studies involving pitfall trapping (Andersen 1997a, Majer 1997). Much of their interest stems from two main characteristics:

1. Australian ants are diverse and, although many of the 4 000 or so species are unnamed, the genera are mostly recognisable unambiguously. As a group, ants are trophically diverse and, therefore, ecologically informative. Local diversity can be high: it is not unusual to exceed 100 species of ants/hectare in parts of the country.
2. This ecological complexity, including associations with a variety of other taxa, has led to designation of a series of 'functional groups' (Greenslade 1978, Andersen 1995), whereby particular ant genera can be allocated (albeit at times tentatively) to a particular category, and richness (based on 'morphospecies') within genera and functional groups related to features and disturbance regimes of the habitats, and ranked to help in assessment of broader diversity. Thus, some genera (such as *Rhytidoponera* Mayr) are 'opportunists' and can become abundant following disturbance in open habitats. Considerable attention has been paid to using ants in monitoring restoration, for example following mining activities when clear patterns of faunal turnover can sometimes occur, and indices of biological integrity devised (Majer & Beeston 1996), reflecting the lessening of numbers of species from those in pristine habitats under different regimes of land use. Parallel functional groups occur in North America, and Andersen (1997a) suggested the likelihood of similar patterns elsewhere in the world. In some ways, ants in Australia seem equivalent to carabids in the northern temperate region, where series of papers (such as those in Stork 1990, Desender *et al.* 1994) have demonstrated a wide variety of ecological groupings of considerable indicator value.

Characteristic levels of ant species richness are gradually being documented, and differ between different regions and habitats. A series of surveys of ants in grasslands at Mount Piper, Victoria yielded around 30 ant morphospecies on each (Miller & New 1997), whereas woodland surveys in the same region revealed around twice this number on each plot (Hinkley & New 1997). These trends are borne out by other surveys in Victoria. Change in the balance of functional groups has both seasonal and habitat quality components, but it is also clear that differing levels of sampling intensity may be needed at similar times of the year in different habitats to obtain reasonably complete inventory samples. Species accumulation curves, for example, asymptote after different sampling periods in grassland and woodland, reflecting different levels of complexity in the ant faunas in these habitats (New *et al.* 1996). For most groups of epigaeic invertebrates, including carabids, such patterns have not yet been investigated or established; phenological patterns are unknown, but similar levels of continuous or interval trapping may be needed to establish the basic parameters for assessment. Any 'spot' samples can be very misleading in the absence of longer term survey data to establish the template against which these can be better appraised.

For most pitfall trapped invertebrates, patchiness of incidence is high — and, therefore, predictability and definable pattern is correspondingly low. A similar inference was drawn by Greenslade (1997) who, writing on Collembola in native grasslands, noted 'intrinsic variation in these ecological systems is too great for a linear response to disturbance to be shown by the invertebrates studied here, which makes it unlikely that a single, reliable indicator can be found'. No congruence was found between species richness of ants, carabids and Collembola, so that use of any of these as a surrogate group alone might be misleading. In relation to ants and Collembola, ground-dwelling Carabidae appear genuinely scarce. This may reflect low ground humidity in many habitats. In discussing the abundance of subcortical carabids in Australia, Baehr (1990) noted that much of the continent has few geophilous ground beetles, but it is intriguing that this paucity seems to extend to the more mesic parts of Australia, in which most surveys have been undertaken.

Another, broader example also indicates the possible place of Carabidae in monitoring and evaluation exercises. In an attempt to determine the indicator values of epigaeic invertebrates in remnant woodland systems in northern Victoria, Yen *et al.* (1996) compared River Red Gum (*Eucalyptus camaldulensis*)-dominated sites, Grey Box (*E. microcarpa*)- dominated sites and cleared land by a combination of pitfall trapping, sweeping and timed direct searches, the programme incorporating 32 sites and extending at intervals for over a year. Thirty five families of Coleoptera were collected, with several of these (Anthicidae, Curculionidae, Elateridae, Mordellidae, Staphylinidae) more abundant than Carabidae in pitfalls. The inference may be that carabids are only one of several beetle families which merit further attention to determine their possible indicator values. In rank abundance of beetle families in these sites, carabids rank 3 (pasture), 4 (Grey Box) and 5 (River Red Gum).

As another example, a temperate region forest context, a trapping programme to evaluate the effects of forest fragmentation on epigaeic invertebrates at Wog Wog, New South Wales (Margules 1992) yielded approximately 554 species of beetles, of which about 432 could not be named to species level. One species of *Notonomus* was appraised in more detail, but 'patchiness' may preclude effective evaluation of trends: Margules noted that two of his plots had very low numbers of the beetle, for no apparent reason. Such differences in abundance may reflect microclimate or other features not yet quantified, but apparently similar plots in a variety of vegetation types commonly yield very different arrays of beetles. The carabid fauna of Wog Wog included representatives of 13 tribes (Davies & Margules 1998), but only 8/45 species accounted for 92% of all individuals. Only five species were represented by 100 or more individuals in that extensive survey of 144 monitoring sites.

Similar heterogeneity was found in Tasmanian eucalypt forests (Michaels & McQuillan 1995), where species richness at particular sites ranged from 4 or 5 (20 year old regeneration sites) to 11 (at one old growth site). Only two common species (*Sloaneana tasmaniae* (Sloan), *Rhabdotus reflexus* (Chaudoir)) occurred at all sites, and 8 species occurred at three or fewer sites. Additional hand-collecting showed that some species (such as *Scopodes tasmanicus* Bates) were probably under-represented in pitfall traps and were common under bark of fallen trees. Michaels and

Table 1. Percentage occurrence of the five most abundant carabid species trapped in different regeneration age classes in *Eucalyptus* forest in southern Tasmania (from Michaels & McQuillan 1995).

Species	Regeneration age (years) 1–3	7–10	20+	old growth
Sloaneana tasmaniae	10	70	10	10
Rhabdotus reflexus	10**	60**	20**	20*
Promecoderus spp.	2	80	7	12
*Mecylothorax ambiguus**	90	10	0	0
Notonomus politus	26	7	1	65

*Winged, all other species flightless.
** As in published table.

McQuillan suggested that Trechini (a diverse group of small taxa frequenting moss and litter) might also have been undersampled. Two points of more general relevance emerge from this study. First, that strong seasonal activity necessitates sampling over most of the year in order to get adequate representation of the fauna and its responses. Second, because many of the species in a survey are local endemics, the degree of valid extrapolation even to other notionally similar forest environments is very limited. Nevertheless, there were some clear differences in the carabid assemblages of different stages of forest regeneration after felling, and the study reported by Michaels and McQuillan (1995) was undertaken in part to investigate parallels of Carabidae in Tasmania to the more extensive studies in North American forests (for example by Holling 1992, Niemela *et al.* 1993) Notwithstanding the low abundance of many species, each of the five most abundant species showed proportional peaks at particular stages of regeneration, and ranged from early successional species to those representative of old growth forest (Table 1). As in other studies, flightless species are assumed to be resident.

5. The future

Development of monitoring techniques using invertebrates is an active field of endeavour in Australia, together with critical evaluation of the techniques and sampling protocols needed to provide reliable information. Debate on the optimal focal groups to appraise is continuing. The shortcomings of pitfall traps are recognised widely, to the extent that more than a dozen contributors to a recent symposium on invertebrate biodiversity (Yen & New 1997) addressed these in some detail.

Despite uncertainty over the most informative invertebrate groups to study in such programmes, ants, spiders (for which a series of functional groups are now definable: Churchill 1997) and Collembola are at present particularly attractive to investigate further. In contrast to the widespread use of carabids in some other parts of the world, there is currently little effective advocacy for the group in Australia, other than by expatriates familiar with their values in the northern hemisphere and who feel that we should be able to do better with groundbeetles here! In temperate southern Australia, in particular, several large and complex longterm trapping programmes for epigaeic invertebrates have been undertaken recently: that by Yen *et al*. noted above is only one example of those which have yielded standard samples from a variety of sites reflecting various forms of land use or ecological gradients, as bases for ordination analyses. The difficulties of obtaining species-level identifications and, therefore, of appraising the samples at the most meaningful level, have retarded analyses of most of these studies. However, morphospecies can usually be delimited consistently within a genus. During the next few years, it is likely that the Carabidae from several of these surveys will be appraised in more detail, following the example set by B. A. Melbourne (unpubl.). At that time, we should be able to more effectively assess their potential as indicators of disturbance or habitat type, not least because the 'typical' habitat of some species of open environments will be defined far more clearly than at present.

At present, our data are fragmentary, our expectations of Carabidae too vague and inconsistent, and there is insufficient detailed knowledge of carabid biology. We are unable to evaluate assemblages of carabids effectively, because of the unknown significance of the numerous rare species, but it is necessary to employ continuous sampling regimes rather than interval trapping to address this effectively, and to gain even reasonable inventory data on regional faunas. Even this more comprehensive approach may reveal many species to be highly unpredictable and patchy in incidence, both in space and time, and direct our attention to more detailed studies of the factors influencing more abundant taxa in the assemblage. At present these are largely unknown and undocumented. Carabid diversity in many Australian temperate regions appears to be generally less than in comparable northern hemisphere systems, with patterns of species dominance also unusual. However, the relatively few abundant species provide clear focal points for investigating responses to environmental change and correlations with land use.

In selecting a suitable portfolio of taxa to use in monitoring land use, condition and change in southern Australia, it is premature to confirm that Carabidae would be included. Nevertheless, in recognising their worth elsewhere, it is equally premature to dismiss them before more critical evaluation of their responses to change.

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